II. SPECIFICATION AMENDMENTS

Please delete the paragraphs beginning at page 4, line 18 through page 7, line 27 beginning with the language "[s]ubstantial research was carried out to develop" on page 4 and ending with the language "[i]t was with knowledge of the foregoing state of the technology that the present invention has been conceived and is now reduced to practice."

Please add the following paragraphs to page 11 after the heading "DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS" on line 9 and before the paragraph beginning with the language "[t]urning now to the drawings and initially to Fig. 1 ..." on line 10 as follows:

Substantial research was carried out to develop thermomechanical means to integrate strengthening and roll finishing in sintered and hardened powder metal steel components. Cylindrical powder metal specimens with up to 15% porosity in the sintered and hardened conditions were surface densified by thermomechanical means to nearly theoretically full density at the surface, to less than 2% porosity at depths of 70-200 microns, and to about 4% porosity at depths of 250-1300 microns. Simultaneous densification and hardening was achieved for SAE 4680 and SAE 46100 powder metal alloy formulations with carbon contents of 0.8% and 1.0% respectively, with associated enhancements in particulate and apparent hardness and performance.

A study was also carried out to evaluate whether a powder metal gear could be ausformed without breaking off the teeth

sequentially during the thermomechanical operation. Rather than starting with a near-net shaped sintered powder metal gear blank, a gear wheel with teeth was machined from cylindrical sintered powder metal blanks of SAE 4680 formulation in order to minimize costs. The study demonstrated the potential for thermomechanical means of rolling and densifying sintered and hardened powder metal gear blanks, but also showed the need for further developments in the specialized shape of the rolling dies required for rolling the sintered and hardened powder metal gear blanks by thermomechanical means to desired accuracy.

These studies have led to the present invention wherein sintered and hardened gear wheels are surface densified, hardened, strengthened and finished to high accuracy by thermomechanical means in the metastable austenitic condition. This simultaneously occurs in the gear tooth flanks and in the root/fillet regions by substantial surface compaction during the rolling operation.

In accordance with the present invention, there is provided a method and apparatus for densification by surface compaction and roll finishing of sintered and hardened powder metal gear wheels by thermomechanical means in the metastable austenitic condition, both on the flanks and in the root/fillet regions of gear teeth, resulting in surface densification to fully dense at the surface and 95-100% in the near surface region. This produces enhanced apparent surface and near surface hardness, improves mechanical properties due to ausforming, and produces a dimensional accuracy and surface finish comparable to or better than hard grinding, thereby eliminating the need for any subsequent finishing operations. The method described herein is applicable to both sintered low carbon alloy powder metal gear

steels that are carburized and hardened prior to the thermomechanical finishing treatment, and to sintered medium to high carbon alloy powder metal gear steels that are induction hardenable. Henceforth, both types of these powder metal gear steels will be referred to as hardened powder metal gear steels.

The method of the present invention for sintered and hardened powder metal gears results in surface densification to 100% theoretical density at the surface, with progressively reducing densification of 95 to 100% produced at least in the outer 400 microns, and possibly up to 1300 microns. Furthermore, as the procedure of the present invention is the final finishing operation for hardened powder metal gears, the full benefit of the surface densification achieved and the related enhanced apparent surface hardness, finished gear strength, accuracy and surface finish, are fully retained. Finally, the plastic deformation induced in the metastable austenitic condition by thermomechanical means induces additional strength due to ausforming effects, thus resulting in further enhanced strength of the gear wheels.

As the powder metal sintered and heat treated gear wheels contain substantial amounts of pores prior to densification with effective density in the range of 90-95% of theoretically fully dense alloy, the rolling dies used for thermomechanical finishing are required to be designed specifically for densification by rolling involving substantial compaction of the material in the tooth surface layers. In contrast, the rolling dies for thermomechanical finishing of gear wheels made of wrought or forged steels are designed for combined rolling and sliding action on the tooth surface layers. The material flow is lateral oriented both in the tangential direction up and down the gear

teeth as well as in the axial direction as no radial compaction of the material is possible. Therefore, for the thermomechanical finishing of powder metal sintered and heat treated gear wheels, the rolling dies apply surface densification pressure resulting in a collapse of the pores near the tooth surface region. This results in densification. The shape of the rolling die, especially the die tooth tips, are designed for conjugacy, for contacting the gear wheel in the regions of interest and for compressing the material.

In order to achieve a nominally involute rolled gear wheel tooth profile in the finished condition for sintered and hardened powder metal steel gears, the rolling dies' tooth profile must substantially deviate from nominal involute tooth geometry. As the method of the present invention involves induction heating of the gear tooth surfaces followed by marquenching to temperatures in the range of 450-500ºF, and then plastic deformation and compaction of surface layers by gear rolling, the rolling dies are maintained at the processing temperature of 450-500ºF and therefore are subjected to substantial thermal expansion. Due to the rolling die thermal expansion, the die tooth profile at the elevated operating temperature is substantially different from the initial rolling die tooth profile at room temperature and as originally produced. Similarly, the gear is not only roll finished at the elevated temperature of 450-500ºF, but is also subjected to localized heating of the surface layers by induction heating followed by marquenching.

The gear is thus subjected to a complex thermal history as well as associated metallurgical transformations. The resulting volumetric dimensional changes in the gear tooth profiles thus result in substantial deviation from the initial gear tooth

profiles at room temperature and as originally produced. The gear teeth in the thermally and metallurgically modified geometrical shape and state are then rolled against the thermally modified rolling dies under high loads and speeds. The gear teeth are thus subjected to plastic deformation and densification at the elevated temperature by rolling pressure applied by the thermally modified rolling dies.

The roll finished and densified gear, still at the elevated temperature, is then finally quenched to room temperature and/or further below the M_f temperature. It is in the finally quenched condition that the sintered, hardened and rolled/densified gear wheel is in conformance with the specified nominally involute gear geometry condition. Predicting and implementing the required initial specialized rolling die tooth profile is critical for achieving the desired contact along the gear wheel tooth surfaces and the desired degree of compaction and densification in the flank and root/fillet regions of the gear teeth.

More recently, in order to produce wrought or forged steel gears with improved accuracy, surface finish and enhanced load carrying capacity, it was recognized that the gear roll finishing process must be applied to both the active contacting surfaces as well as the trochoidal root fillet regions of the helical gear teeth, and apparatus and methods to this end have been disclosed in U.S. Application Serial No. 10/056,928 of Nagesh Sonti et al. As therein explained, if the roll finishing operation were extended to finish the root/fillet regions in addition to the active contacting surfaces of the gear teeth, then the surface finish and bending fatigue strength of the gear teeth would be substantially improved. Root fillet regions of gear teeth experience the maximum bending stress. Roll finishing of the

root/fillet regions improves the surface finish, thereby reducing the stress concentration, and enhance the fatigue resistance of the material due to plastic working.

It was with knowledge of the foregoing state of the technology that the present invention has been conceived and is now reduced to practice.